TITLE OF PAPER: Twin-Screw Extruder Safety Demonstration Tests

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ABSTRACT

Thiokol Corporation installed a Werner & Pfleiderer twin-screw extruder at the Longhorn Division in Marshall, Texas in 1988. A number of modifications to the installation have been made for safety and operational considerations. This paper will review the current installation and discuss some of the modifications and some of the processing results from operation of the system.

The facility has been used to process live composite propellant in the mixer mode including casting of samples and test motors. The latest work includes processing in the mixer mode for applications such as infrared decoy flare compositions. The facility is considered a state-of-the-art installation for continuous processing with broad capabilities and special consideration for processing energetic materials.

Introduction

Twin-screw extruders have been used for many years in Europe to process a wide variety of propellants and explosives. US interest in this processing technology has been under serious consideration for about the past 7 years. Most of the initial studies in the US were made with inert materials on Werner & Pfleiderer twin-screw extruders. Since then, several US facilities have processed live energetic compositions using either the W&P machines or an APV (the former Baker-Perkins) machine. These facilities include NSWC-White Oak, NOS-Indian Head, UPCO, UTC and, of course, Thiokol.

The initial studies of twin-screw extruder processing used Werner & Pfleiderer (W&P) twin-screw extruders of a modular barrel design. This modular design offered flexibility in setup since the barrel modules could be arranged to give any configuration of feed ports, process sections and vacuum ports desired. A major problem identified with this design concerned the problem of jamming of the screws due to feed problems. If the screws become jammed, the modular barrel design must be disassembled by disconnecting the screw shaft coupling and pulling the screws through the barrels with live material on the surfaces, or by unbolting each section of the barrel and pulling the barrel section over the shafts, again with live material on the surfaces. This was determined to be unacceptable practice under US safety standards. Thiokol worked with a W&P 30mm twin-screw extruder for over a year processing inert propellants. This background work developed the information to define the necessary changes to provide safety in operation. Hazards analyses from NOS-IH and Southwest Research Institute (for ARDEC) along with Longhorn developed process information were used in discussions with W&P to define the requirements for a safe twin-screw extruder design for processing energetic materials. W&P designed a split barrel extruder that could be remotely opened

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in case of screw jamming and also incorporated many other design features specifically engineered for safety. After detailed review of the new design and additional requirement definition, W&P built the first twin-screw extruder designed specifically for energetic material processing for Longhorn.

The extruder has a nominal screw diameter of 58mm (2.3 in.) and a barrel length of 1440mm (56.7 in.) The length of the assembled screw elements on the shaft is 1440mm. This gives an L/D ratio of 24:1. Screw elements are available in several combinations of length and pitch. The elements are assembled on splined shafts and end caps are torqued to a minimum of 75 ft-lb.

There are three tempered zones in the extruder barrels and a fourth tempered zone in the die head when using direct extrusion. The tempered zones are temperature controlled by pumping heated water from Mokon hot water heaters through the barrel sections. The Mokons are capable of heating the water to 300 °F.

The top barrel section has four openings into the bore of the extruder. The first opening is near the back of the barrel for feeding polymers or slurries to the extruder. This port is approximately 0.25 in. in diameter. The second port is also near the back of the extruder and is a large (4x5 in.) opening for feeding solids to the extruder. This is followed closely by another liquid feed port, also 0.25 in. in diameter. Near the discharge end of the extruder, there is a large opening (4x8 in.) used for removing volatile solvents or gases from the composition. A vacuum vent is attached to this port and a water-seal vacuum pump is used to draw off volatiles.

The extruder is powered by a 50 HP General Electric DC motor. The barrels are split along the horizontal axis and can be remotely opened to clear a blockage or for inspection. There are three hydraulic cylinders to open and close the barrel halves. The cylinders are suspended from the top barrel and push the top up two screw diameters until reaching fixed stops. Continued application of hydraulic pressure causes the bottom barrel to be pushed down against four springs that serve as supports. When the barrels reach the full open position, a locking ring on the center cylinder snaps into place to hold the barrels open, even if hydraulic pressure is lost. When closing, the hydraulic pressure first opens the lock ring and then brings the barrel sections back to the closed position. All three cylinders have locking rings in the closed position to keep the barrels from opening if hydraulic pressure is lost during a run. Alignment pins assure that the barrel halves are positioned properly relative to the shafts and bearings.

The first live runs of energetic material were accomplished in August, 1989 using an aluminized composite propellant formulation. The runs led to the manufacture of over 500 lb of propellant for test and evaluation. Test motors and 70 lb BATES motors were cast and fired in the initial tests. All ballistic parameters were met and physical properties and compositional analyses were excellent. In a follow-on to the initial propellant work, over 500 lb of a thermoplastic elastomer propellant were processed on the extruder. Preliminary tests on this material showed nominal performance.

Infrared decoy flare composition is extremely hazardous to process by current methods. Figure 1. shows a block diagram of two actual processes for manufacture of flare composition and a third proposed process. The separate elements of the block diagram for the continuous processing have been demonstrated on the twin-screw extruder facility. Live flare composition was processed on the twin-screw extruder in the mixer mode and pressed into test pellets. The pellets were finished with normal production handling and tested in the test tunnel. Performance was excellent with all test parameters met. Reproducibility was excellent even though the material is in the mixer for only about 2 minutes. Future efforts will include developing criteria and techniques for processing in the extruder mode. One of the main safety features is the low amount of material in process at any time. The extruder is run starve-fed with approximately 2 lb of composition in the barrels at once. The solvent content of the flare composition can be reduced through the use of vacuum at the vacuum port. Figure 2. shows an artist's concept of a proposed remote processing concept for flare composition.

Safety Tests

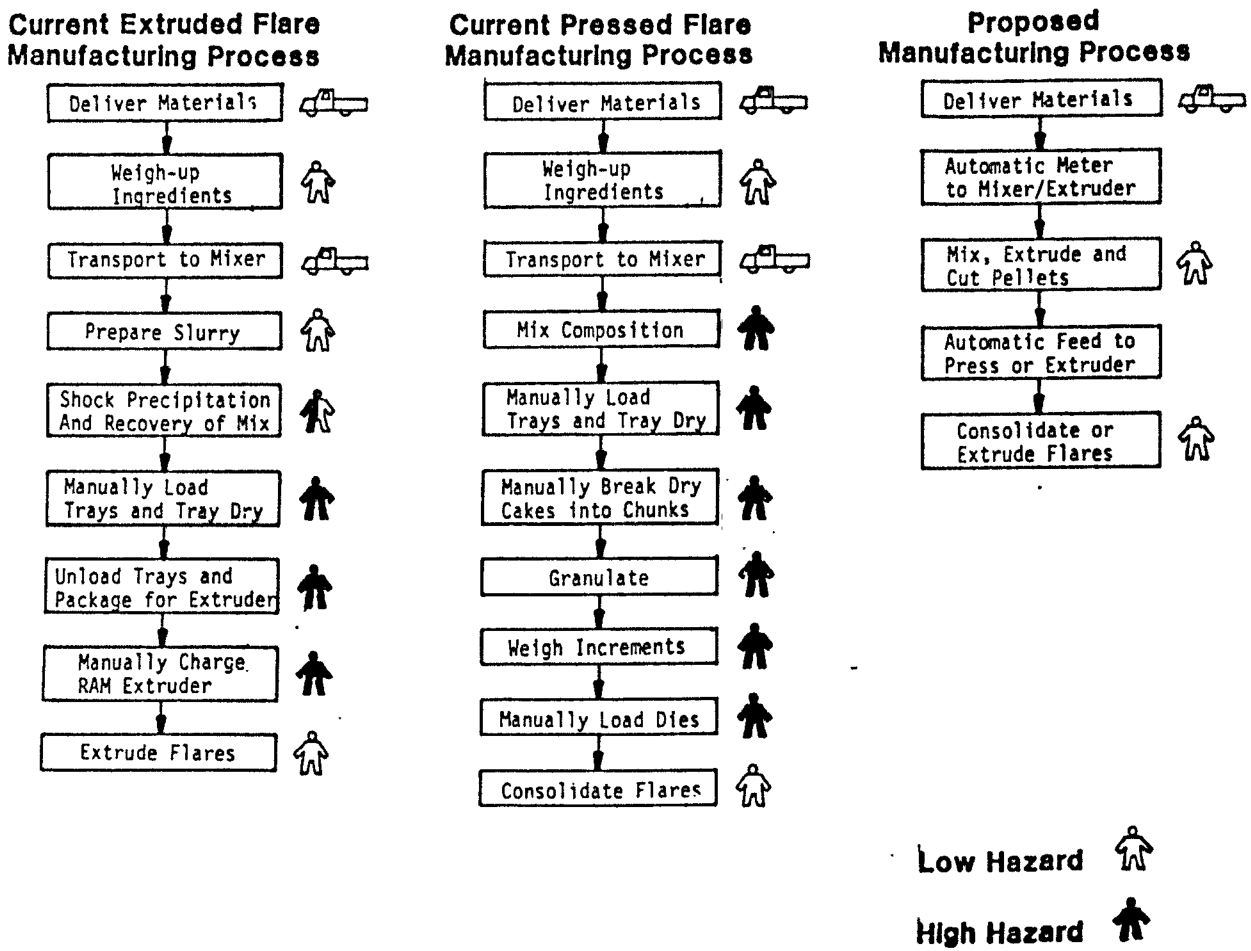
In all of the early work reported, there is no documented incident of an ignition in a twin-screw extruder while the machine was running. The few incidents that have been reported are generally of the "cook-off" variety or due to operator intervention with the product while the machine was stopped. In evaluating the new design for twin-screw extruders from Werner & Pfleiderer, Thiokol, Army and Navy hazards analyses posed concerns that certain operations could lead to ignition within the barrels while the extruder was in operation. Since there was no direct evidence to indicate how severe this incident would be, some tests were planned under the Thiokol IR&D program.

To prepare for these tests, arrangements were made with Werner & Pfleiderer to lease some old ZSK-53 extruder parts to build a mock-up of a twin-screw extruder. The ZSK-53 parts obtained included 8 barrel modules, a pair of screw shafts, and enough triple lobe screw elements to fill the shafts fully. A local contractor fabricated a drive unit utilizing a 9 HP air motor driving sprockets on the shaft ends with a "bicycle chain". A skid was built to hold the drive unit and support the barrels. No attempt was made to optimize the support and alignment system to prevent contact of the screws with the barrels. In these planned tests, the extruder was stopped and restarted with live material in the barrels to test the worst possible conditions.

The trials were run in an open field in one of the test areas at Longhorn. For the initial trials, the compositions were pre-mixed and charged into the extruder at the test site.

The first test consisted of an infrared decoy flare composition. A production formulation was chosen with known output characteristics and sensitivity. A standard mix was made and delivered to the test site. The extruder was set up about 75 feet from a bunker with air lines from a large compressor providing the air to drive the gears. The feed port was fitted with an aluminum pipe to serve as a feed funnel simulating the ZSK-58E. A die plate with a 1/2 in.

REDUCED HAZARDS FLARE MANUFACTURING



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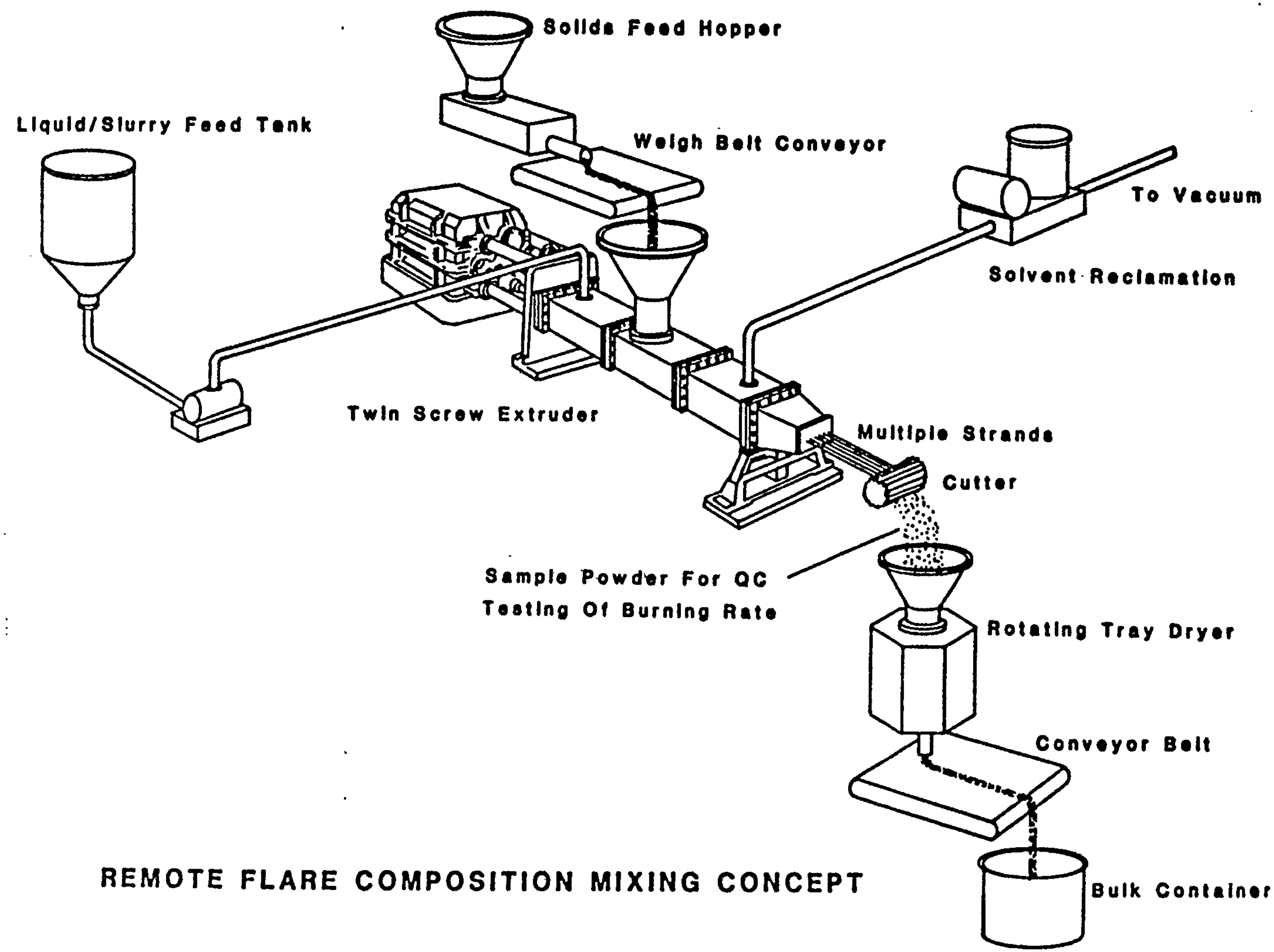

REMOTE FLARE COMPOSITION MIXING CONCEPT

diameter orifice was added to the extruder end to simulate the extrusion of the flare composition. Approximately 2 lb of the flare composition was loaded into the feed funnel and an aluminum follower plug was inserted to force the flare composition into the screws. The air motor was turned on from behind the bunker and the screw speed was adjusted to 20 rpm. When it was determined that flare composition was extruding through the die plate, an electric match was fired in a small bag of black powder to ignite the flare composition near the extrusion end of the barrels. The screws were kept turning during the entire test. The flare composition burned for approximately 20 seconds before reaching the funnel area. The confinement of the follower plug produced a surge in burning that blew the follower plug out of the funnel. It was found that the flame did not propagate through the die area and the extruded material did not ignite. The extruder was disassembled and inspected after the test and all of the parts were in satisfactory condition.

In the second test, a batch of LOVA propellant was produced in a vertical mixer for testing. LOVA is the acronym for LOw Vulnerability Ammunition. It is a propellant designed to extinguish at atmospheric pressures to protect tank crews from their own propellant in the event of penetration of the ammunition in the tank. The test was set up the same as before. The LOVA propellant is a solvent-based system with ethyl acetate and ethyl alcohol solvents. When the igniter functioned, the solvents ignited and burned for about 2 minutes. When the solvent had burned away, the propellant did not ignite and the flame went out. This test went as expected, since the propellant does not sustain combustion under these conditions.

The third test was considered the most severe. A typical composite solid propellant was chosen for testing. This propellant is relatively energetic and has a known pressure exponent. It was sure to burn vigorously during the test. The propellant mix was made in a vertical mixer without the addition of the cure agent. This provided an extended pot life for testing. The funnel on the extruder was reduced in length and no follower plug was used with the propellant. The die plate was removed to simulate using the extruder in the mixer mode. Approximately 2 lb of propellant was placed in the funnel and the extruder screws were started. After it was observed that the propellant had filled the extruder barrels, the igniter was fired. The propellant quickly burned through the short distance to the extrusion end and ignited the propellant on the ground. After about 10 seconds, the flames progressed to the feed port and there was a muffled boom. Upon inspection of the extruder, it was noted that the aluminum plate used to hold the igniter had been bent significantly. It may be noted that the plate had been subjected to approximately 10 seconds of heating in a 5000 °F flame. When the extruder was cleaned and inspected, it was determined that the extruder parts were undamaged by the test.

The main point to be made by these tests was that there was no major damage or indication of severe hazard associated with ignition in the extruder while the screws were turning. This was considered an "overtest" since the ZSK-58E has provision for opening the split barrels and deluging the extruder. This would further mitigate the effects of an ignition. Automatic sensing of an anomalous temperature rise will be tested.

A fourth test was carried out to evaluate the effects of contamination of a propellant with particles that were too small to effectively screen out of the system. Screens capable of preventing the entry of nuts, bolts or other large contaminants into the extruder barrels have been incorporated in the system already. Since the clearance between screws and walls is nominally 787 microns and the clearance between screws is 787 microns, it was necessary to determine the effect of small particles on the hazards with contaminated propellant. The particle size distribution of the steel grit and sand used for these tests is shown in Table 1.

Table 1.
Particle Size Distribution

		Cumulative Wt. %	
Screen	Opening,(microns)	Sand	Steel Grit
10	1910	13	0
16	1130	19	0
20	860	24	0
30	520	32	13
60	230	77	99
Pan	-	100	100

It is felt that 30 mesh screens would be the maximum that can be used for screening materials on a practical basis. If 16 mesh could be used for some materials, it would be a definite processing advantage. The remaining composite propellant used in the third test was chosen for this test. To evaluate the statistical probability of an ignition due to the incorporation of a small contaminant, 1% of sand and 1% of steel grit were added to the propellant. The propellant was then to be cycled through the extruder 20 times. Due to the age of the propellant, the viscosity had become very high and the material did not feed well in the extruder. There was a section of kneading blocks in the extruder to provide a "worst case" test. The propellant finally passed through the screws into a catch bucket. There was no ignition of the propellant during the first run, but due to the extreme difficulty in feeding, it was decided to terminate this test. The very high viscosity of this propellant caused the extruder to essentially granulate the mix. This resulted in a large surface area that would lead to a high rate of flame propagation. Under normal processing conditions, material would not be processed in this dry state.

It was decided that the ignition test would be conducted on this mix to assess the severity of the expected high burn rate on the extruder. The feed funnel was emptied of mixed propellant and 70 gm. of unground ammonium perchlorate was poured into the feed port. This was followed by 30 gm. of HTPB/Al slurry. The extruder was run for 30 sec to simulate the conditions expected at the feed port with unmixed propellant. An igniter was fired in the vacuum port to simulate an ignition. After approximately 1 second, there was a loud boom at the extruder. The aluminum feed funnel was split and ripped off the extruder. Two sections had closure plates blown out of the barrel. The skid the barrel was mounted on allowed the downward force of the closure plate ejection to bend the barrel down and stretch the connecting bolts. Gaps were now visible between some of the barrel sections. The end caps that hold the screw elements on the shafts were elongated and cracked near the ends. Two screw elements had cracked at the interface to the next screw. The barrel sections were not severely damaged. New bolts and new screw element end caps were obtained and the two screw elements were machined off to eliminate the damaged sections. The extruder is now operational for additional testing. This is considered to have been a very severe test with contaminants covering a wide range of particle sizes in a mockup that permitted very harsh conditions to exist, including restarting the screws with live material in the barrels. It should be pointed out that this was a deliberate ignition of the system, and that the grit/sand mixture did not cause the ignition. In none of these severe condition tests was there an unintentional ignition of the energetic materials.

In conclusion, the tests conducted to date in the twin-screw extruder mockup have indicated that the original assumptions concerning the safety of the twin-screw extruder in processing energetics were justified. Future plans include more safety tests with the extruder mockup to gain more knowledge of possible failure modes and the results of accidental ignition.